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BRIGHTNESS COMPARISON OF ELECTROLUMINESCENT VERSUS INCANDESCENT LIGHTING: A PHOTOMETRIC VALIDATION

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AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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Previous studies involving the brightness comparison of electroluminescent (EL) versus incandescent (INC) lighting indicated that observers saw the EL light as being "brighter" than the INC light even when both lights were photometrically identical. The intent of this experiment was to determine if a perceptual process was present that inhibited the direct photometric measurement of EL lighting. Twelve observers were asked to compare a variable EL light with a fixed INC light. Nine different brightness levels of the EL light were tested. Subjects were asked to rate if the test lamp (EL) was higher, lower, or the same as the reference lamp (INC). The results from this study showed no difference between the two types of lighting; this in turn validates the use of photometry to measure EL lighting directly.

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SUMMARY

Electroluminescent (EL) lighting has been proposed as an alternative lighting that would eliminate several problems associated with current incandescent (INC) lighting in aircraft (glare, infrared rays, "hot" spots, etc.). The use of photometry to measure EL lighting has been questioned since previous studies indicated that EL lighting appeared to be "brighter" than INC lighting, even when both light sources were photometrically identical. The following describes the experimental exposure:

* Observers were twelve naive subjects, both male and female, aged 19-29.

* Subjects were asked to compare a variable EL light with a fixed INC light.

* Nine different brightness levels of the EL light were tested six times each for a total of 54 trials. Brightness levels were determined as percentage differences of the fixed INC luminance of 4.90 fL.

* Brightness levels ranging from -20% to +20% in 5% increments were used in the experiment: 3.92, 4.17, 4.41, 4.66, 4.90, 5.15, 5.39, 5.64, and 5.88 foot lamberts, respectively.

* Observers were asked to rate if the test lamp (EL) was higher, lower, or the same as the reference lamp (INC).

The results from this experiment were the following:

* The group mean and standard deviation obtained were respectively, $x = 4.82$, $s = 0.534$.

* A Student's t-test which compared the obtained group data with the EL and INC lights matching luminance of 4.90 was not significant, $p < .05$.

* The relationship between percentage of "HIGH" responses and luminance of the test lamp was a linear increasing function with $r = 0.98$.

* A plot of percentage of "LOW" responses as a function of test lamp luminance was a linear decreasing function with $r = 0.97$.

The results show that direct photometric measurements using current photometric instrumentation and procedures are valid and may be used to thoroughly evaluate this type of lighting for future aircrew configurations.

PREFACE

The research described in this report was completed at the Air Force Aerospace Medical Research Laboratory, Human Engineering Division, Crew Systems Effectiveness Branch as a part of Project 7184 12 15. This study was funded by the PRAM SPO (ASD/RAOE) of Aeronautical Systems Division.

I am indebted to Dr. Harry L. Task for his guidance during this research. His knowledge and expertise were most appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Lighting, both in and out of the crew station, has been a critical factor in the success of Air Force missions. Incandescent (INC) lighting has been the standard for many years, but as the technology has become more advanced, new types of lighting are now being considered as alternatives to incandescence. Before integrating them into Air Force applications, different types of lighting configurations should be evaluated thoroughly. The intent of this report is to describe one relatively new type of lighting, electroluminescent (EL) and to determine if standard photometric techniques may be used to measure it.

Basically, an EL lamp is a capacitor - it has a dielectric material sandwiched between two conducting surfaces. The luminescent phosphor is scattered within the insulator so that it may lie in the path of the electrostatic field. Electric bus bars are mounted to the top transparent conductor, and finally a mylar coating is added to retard moisture. The entire lamp is then laminated in plastic to complete the construction. When an alternating current is applied, the changing electric field causes current to flow within the phosphor particles embedded in the insulator. The induced current causes the electrons in the phosphor to jump energy levels, thereby giving rise to "luminescence" - the emission of light not due to temperature of the source.

The main advantage of EL lighting is the even distribution of luminance across the face of the lamp. This is unlike the INC lamp, whose intensity is brightest at the center and falls off as the distance from the center increases. EL lamps have been considered for Air Force lighting applications for other reasons as well:

1. Dependable - major catastrophic failures eliminated
2. Shapes and lamp design can be easily specified
3. Available in several colors: white, yellow, green, and red
4. Light intensity controlled over a wide range
5. No significant color change when dimmed
6. Readily withstand vibrations
7. Emit no ultraviolet and few infrared rays
8. Relatively narrow spectrum of emission
9. "Cold" source - heat loss is minimal

Recently, questions have been raised about using standard photometric techniques to measure EL lamps. Previous studies involving some comparison between EL and INC (Blouin, 1978) indicated that observers saw the EL lamp as being "brighter" in appearance than the INC even when the two sources were photometrically the same. This would seem to indicate that some perceptual process was present that invalidated direct photometric measurements of EL lighting.

This experiment was formulated to define any perceptual differences between EL and INC. If no difference existed, then photometry could be applied for measuring EL lighting. In theory, the photometer should have the same response as a human eye. An observed perceptual difference would result in a "scaling factor" that should be used for EL lighting measurements.

It was hypothesized that in previous experiments some parameters were not properly controlled, and a physical inequality was somehow present between the two lights. This resulted in observers judging the EL to be "brighter" than the INC, even when they were photometrically the same. For example, if the luminance of the INC lamp is not properly diffused, observers will always judge the light to be dimmer than an EL since the first part of any target examined is its edges, and an improperly diffused INC lamp will appear dim around the edges. It was the aim of this experiment to eliminate any previous confounding variables, and to determine if the lights were perceptually different to observers once they were made physically similar. The result would be a validation of standard photometric techniques for EL lighting.

METHOD

Subjects

Twelve naive subjects, males and females aged 19-29 participated in the experiment. All observers were required to have 20/20 or corrected visual acuity as measured by a projected standard Snellen wall chart prior to engaging in the study. Before participating in the experiment, all subjects were asked to sign a consent form provided by the experimenter. A copy of this form can be found in Appendix A.

Apparatus

The apparatus consisted of two light sources, one incandescent (INC) and the other electroluminescent (EL). The light sources were separately contained in metal boxes with black exteriors and flat white interiors having dimensions 8 X 6 X 3.5 inches. A circle of 1/2 inch diameter was drilled into the center of the front face of each metal box. This diameter was chosen so that a large surface area would not be a factor in the judgment of the two lamps. The boxes were placed together with their sides touching on a table covered with black cloth; the resulting distance between the centers of the two circles on the front face of the boxes was eight inches.

The EL light, a flat panel, thick film lamp manufactured by EL Products, Inc., was taped on the interior front face of one box across the circular cut-out area. The EL lamp operated at 400 Hz AC, and was connected to a California Instruments AC Power Source Model 251 T so that the luminance of the EL panel could be varied by the experimenter.

The INC lamp consisted of four 2 watt bulbs arranged in a two inch square in the interior back face of the other box. A white Plexiglas W-2159 diffusive plate was placed on the interior front face of the box across the drilled out circular area to help scatter the light within the box. In addition, two Oriel infrared filters were placed in this region to block any infrared (IR) energy, since the EL lamp in comparison has little IR energy. The INC lamp was powered by a Lambda 20 Volt Regulated Power Supply. A picture of both lamps together as seen by the observer is illustrated in Figure 1.

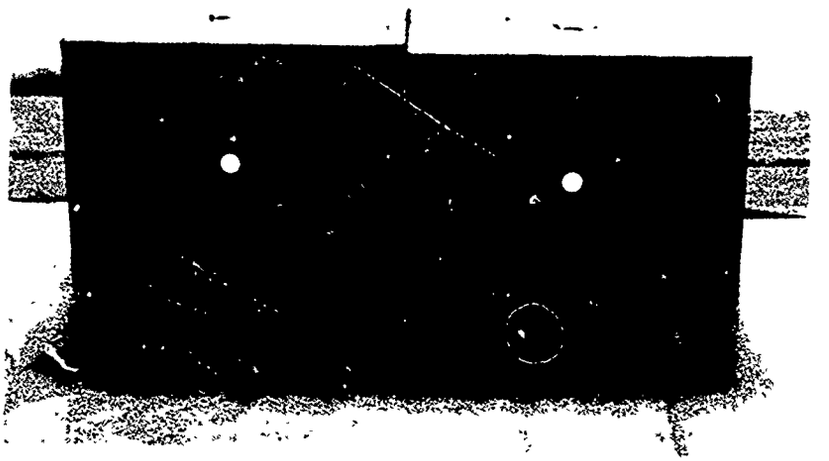

Figure 1. Illustration of Both Lamps as Seen by Observer

To determine the appropriate filters needed for the INC to match the EL in color, a trial and error method was used. The luminance of the INC lamp was measured by a Pritchard 1980B photometer, and then the luminance of the EL lamp was set to this value. Using a Pritchard 1980B Spectraradiometer, the spectral distribution of the EL lamp was determined. Several filters were added to the INC box; a spectral scan was completed, and the EL and INC scans were compared. Depending on the outcome of this process, either the luminance of the EL lamp was adjusted, more filters were added to the INC lamp, or a combination of both procedures was used. This process was continued until both lamps had an identical luminance of 4.90 fL, and the color difference betweent the two was negligible. As a result of this procedure, the following filters were placed in the same circular region on the INC light box as described above:

1. Two (2) Edmund Scientific No. 878 light yellow green filters
2. One (1) Edmund Scientific No. 858 light blue green filter
3. Two (2) Kodak No. 80D Wratten gelatin filters
4. Two (2) infrared blocking filters

Figure 2 illustrates the color coordinates of the two light sources plotted in CIE 1931 space; Figure 3 shows the same coordinates in UCS 1976 space, and Figure 4 plots the spectral distributions for both lamps.

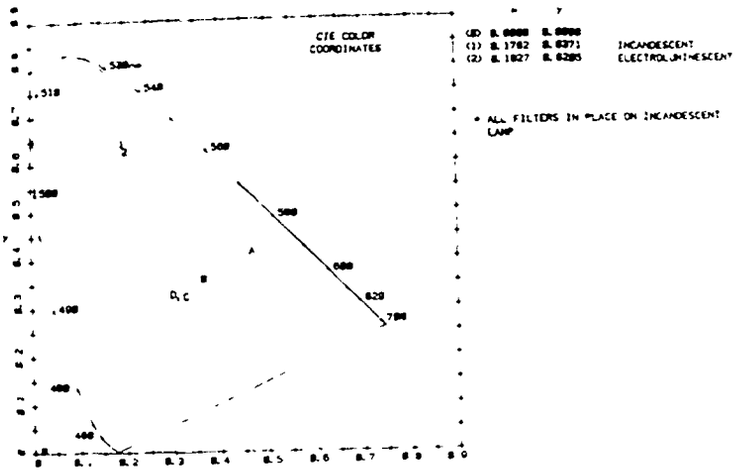

Figure 2. INC and EL Lights Plotted in CIE 1931 Space.

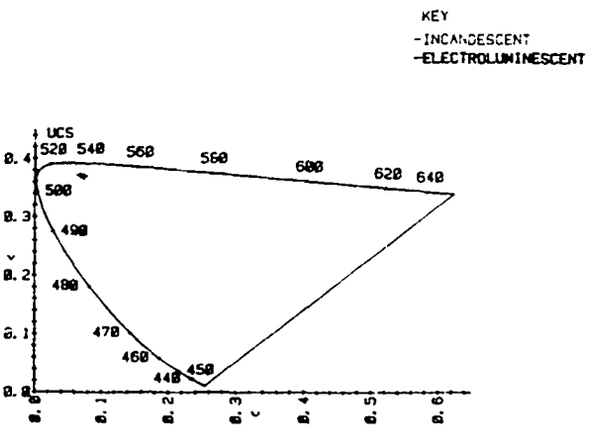

Figure 3. INC and EL Lights Plotted in UCS 1976 Space

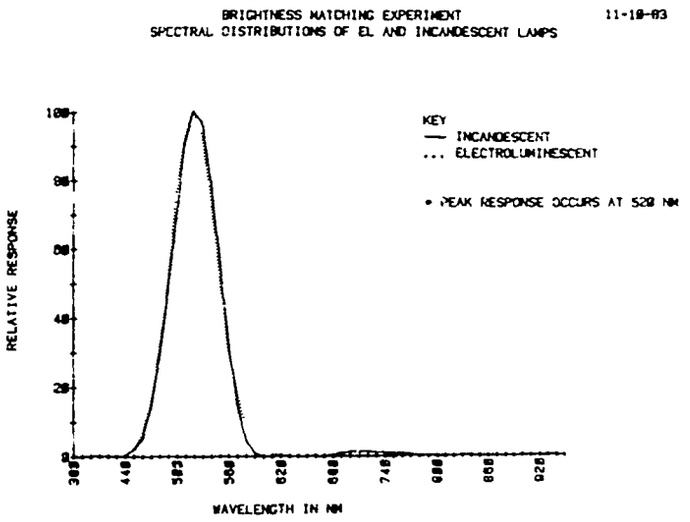

Figure 4. Spectral Distributions of EL and INC Lights

In order for an observer to make an accurate comparison of the intensities of the lamps, the luminance across the front viewing surfaces of the boxes must be uniform. The luminance across each front circular area was measured by a Pritchard 1980B photometer with a Spectar LF-19 microscopic lens, and output to a HP 7100B strip chart recorder. (All of the previously described filters were in place on the INC lamp.) Both lamps fulfilled the requirement of a uniform distribution, as indicated by Figures 5 (INC) and 6 (EL).

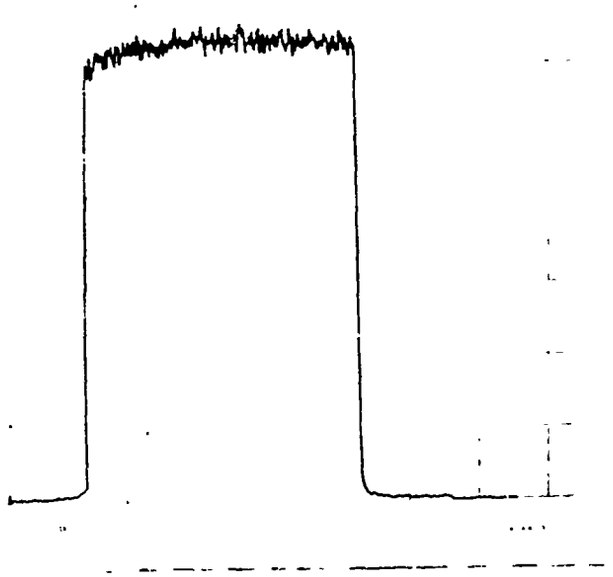

Chart speed = 0.2 in/sec
Range 5 volts/div
Slit Aperture

Figure 5. Incandescent Light Luminance Scan

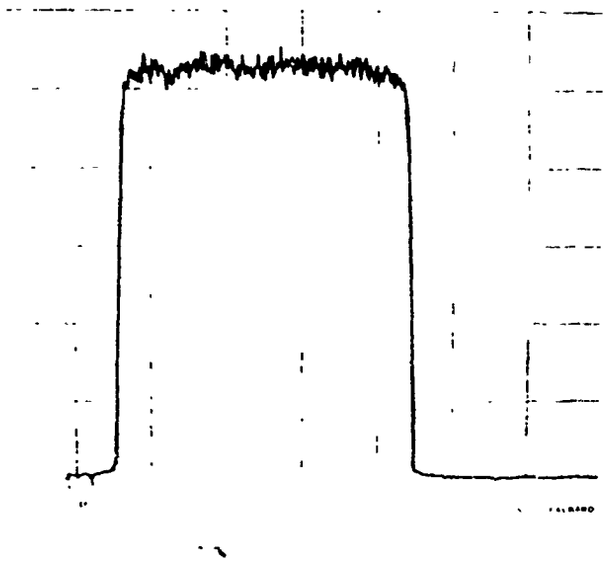

Chart Speed = 0.2 in/sec
Range: 5 volts/div
Slit Aperture

Figure 6. Electroluminescent Light Luminance Scan

The observer was seated 13 feet from the two lights in order that no texture cues from the EL lamp would be present to help him distinguish between the two different lamps. A partition was placed on either side of the cloth-covered table so that the subject was able to concentrate fully on the task at hand. Two 60 watt desk lamps were located within the testing room to add some ambient illumination to the test area. The average room luminance was recorded at 0.008 fL using a Pritchard 1980B photometer. This same photometer was aimed directly at the EL light to record luminance levels, and placed to the subject's left. The view from the observer's chair is shown in Figure 7.

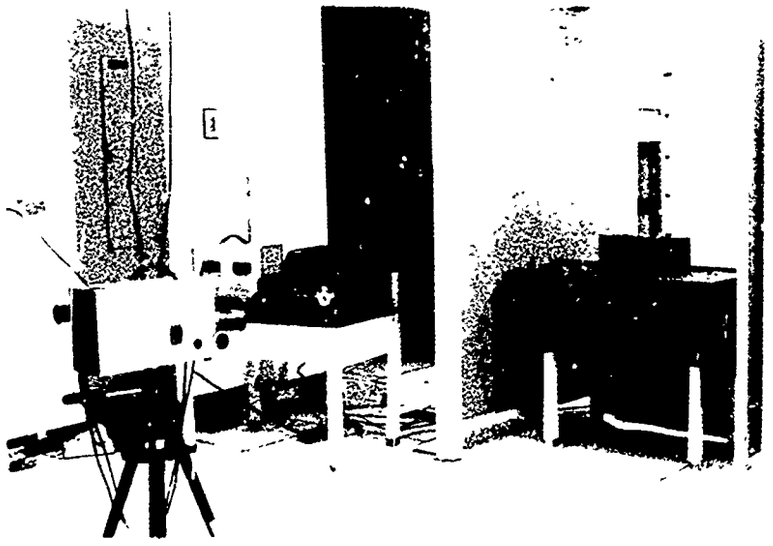

Figure 7. View from Observer's Position

The experimenter's station, located to the left front of the observer's position, consisted of the AC power source and the Pritchard 1980B control console situated on a table facing the experimenter. The subject was unable to see the direction of any luminance adjustments made by the experimenter, and also the corresponding output on the control console. Figure 8 is an illustration of the experimenter's station.

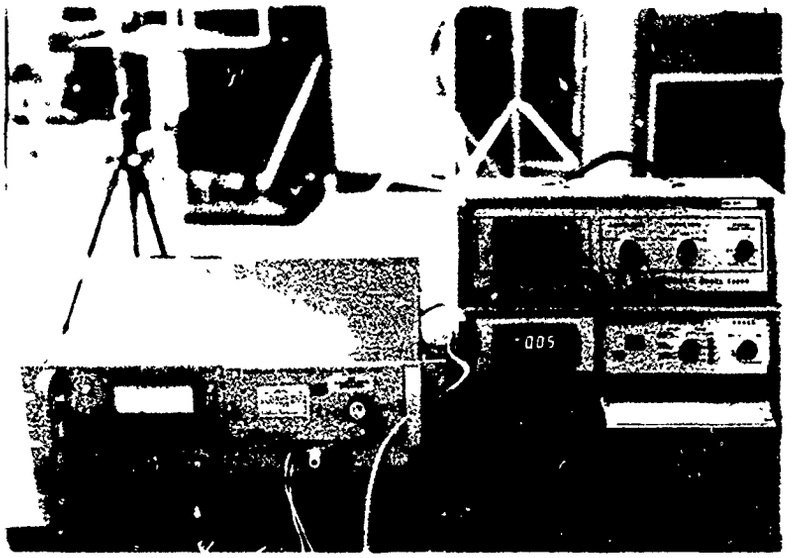

Figure 8. Illustration of Experimenter's Station

Procedure

After the instructions were read to the observer and the consent form was signed, a rest period of five minutes ensued wherein the subject was given the opportunity to adapt to the luminance in the testing room. When this period was over, the testing began. The consent form and instructions can be found in Appendices A and B, respectively.

The experimenter then proceeded to set the first brightness level on the EL lamp using the variable control knob on the AC power source after directing the subject to cover his eyes while the testing level was set. After the experimenter indicated that he was ready to begin, the observer opened his eyes and looked at the two lamps. The participant was asked to compare the intensity of the test light (EL), which was the lamp to the observer's left, with the intensity of the reference light (INC), which was the lamp on the observer's right. If the left light was brighter in intensity than the right light, the subject was told to respond, "HIGH". If the left light was dimmer in intensity than the right light the observer was asked to respond, "LOW". If there was no difference in the intensity of the lights, the observer was directed to reply, "SAME". Immediately after the subject responded, he was told to cover his eyes while the next brightness level was set. This entire procedure was repeated for a total of 54 trials.

Using the above procedure, nine different brightness levels were tested. Brightness levels were determined as percentage differences from the INC and EL matching luminance of 4.90 fL. The percentage differences tested varied in the range of -20% to +20% in +5% increments: -20%, -15%, -10%, -5%, 0%, 5%, 10%, 15%, and 20%. A repeated measures design was used to test each separate brightness level a total of six times. All levels of brightness were block randomized using a random number generator. Table 1 is a listing of the percentage difference from the matching luminance (4.90 fL) and the corresponding EL luminance used to set each brightness level during the experiment.

TABLE 1

EXPERIMENTAL BRIGHTNESS LEVELS

*REFERENCE LUMINANCE = 4.90 fL

% DIFFERENCE FROM REFERENCE	CORRESPONDING LUMINANCE (IN fL)
-20	3.92
-15	4.17
-10	4.41
- 5	4.66
0	4.90
+ 5	5.15
+10	5.39
+15	5.64
+20	5.88

RESULTS

In the past, subjects in other experiments involving some comparison between EL and INC light indicated that the EL always seemed "brighter" than the INC, even when the lamps were at the same luminance level. The purpose for this entire experiment was to determine if in fact a perceptual difference was seen between the two lamps. If a difference did exist, then direct photometric measurements aren't valid, and a "scaling factor" for EL lighting would have to be calculated to compensate for this difference.

To determine if a perceptual difference was present between the two lamps, the number of times the observer made a response of "SAME" was tabulated for each luminance level. These tabulations were converted into percentages and plotted as a function of the luminance of the EL lamp. The individual subject plots can be found in Figures 9-20, and the combined group data is seen in Figure 21. Theoretically, the responses should assume a normal distribution with a mean occurring at the matching luminance of 4.90 fL. Since a random sampling of the population was tested, any perceptual difference between the two types of lighting would result in the group data having a normal distribution with a mean that deviated significantly from the matching luminance of 4.90 fL. Individual subject means as well as the combined group data are shown in Table 2. By examining Table 2, it can be seen that the group observation yielded the following results: $\bar{x} = 4.82$, $s = 0.53$. To test the significance of the obtained experimental group mean from the matching luminance, a Student's t-test was performed. The results of the test were not significant, $p < .05$.

TABLE 2

MEANS AND STANDARD DEVIATIONS FOR RESPONSES OF "SAME"

*MATCHING EL LUMINANCE = 4.90 fL

SUBJECT #	MEAN	STANDARD DEVIATION
1	5.20	0.56
2	4.90	0.50
3	4.74	0.25
4	4.90	0.56
5	4.68	0.44
6	4.66	0.46
7	5.02	0.64
8	4.72	0.40
9	4.93	0.62
10	4.74	0.66
11	4.47	0.50
12	4.60	0.60
*GROUP	4.82	0.53

If the individual subject plots are examined (Figures 9-20), it is apparent that some observers were quite adept at judging the intensities of the lights while others made their judgments with some difficulty. When questioned following the experiment, the subjects who made their judgments with ease indicated that they had set a certain criterion in the beginning trials, and had retained the same criterion throughout the entire experiment. It is obvious that subjects #5, #9, and #10 did not develop any criterion to help them with their judgments. Other observers actually required more luminance from the EL lamp to match the INC lamp. Subjects #1 and #10 illustrate this point.

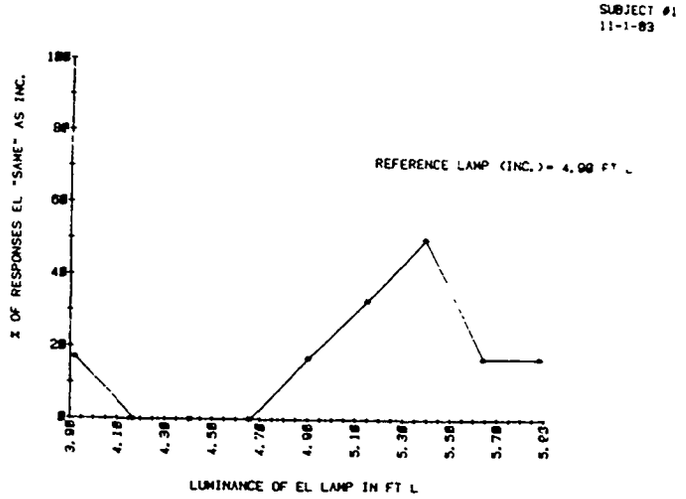

Figure 9. % of "SAME" Responses vs. Luminance of EL Lamp in fL for Subject #1

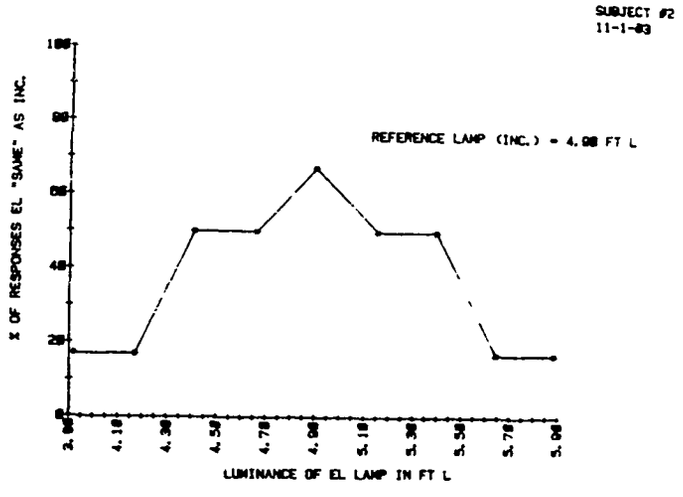

Figure 10. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #2

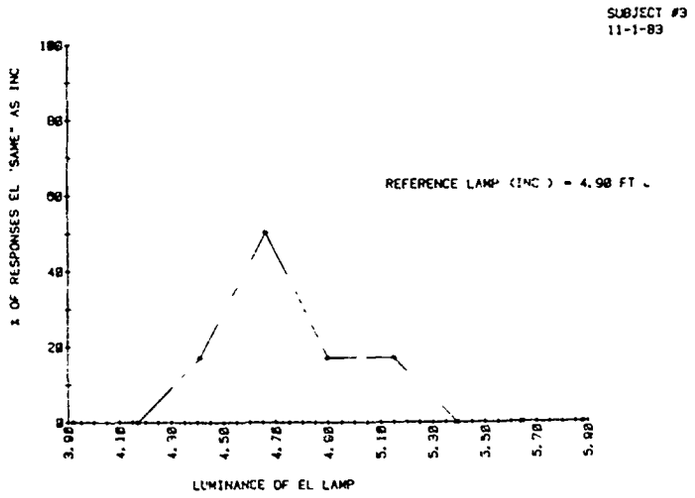

Figure 11. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #3

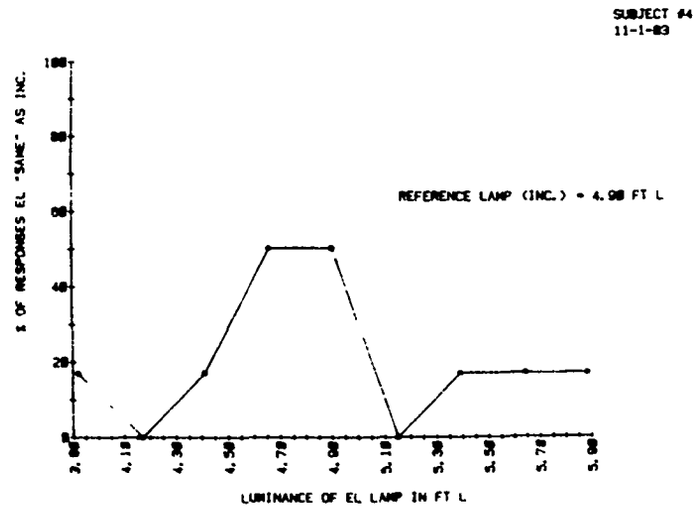

Figure 12. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #4

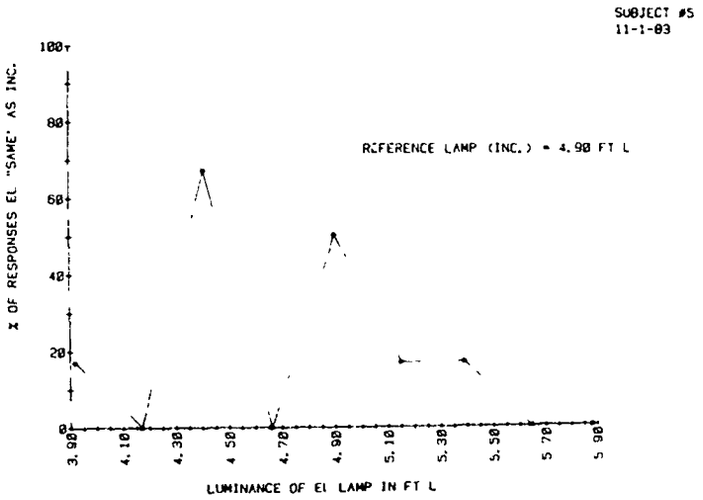

Figure 13. % of "SAME" Responses vs. Luminance of EL Light in fL for Subject #5

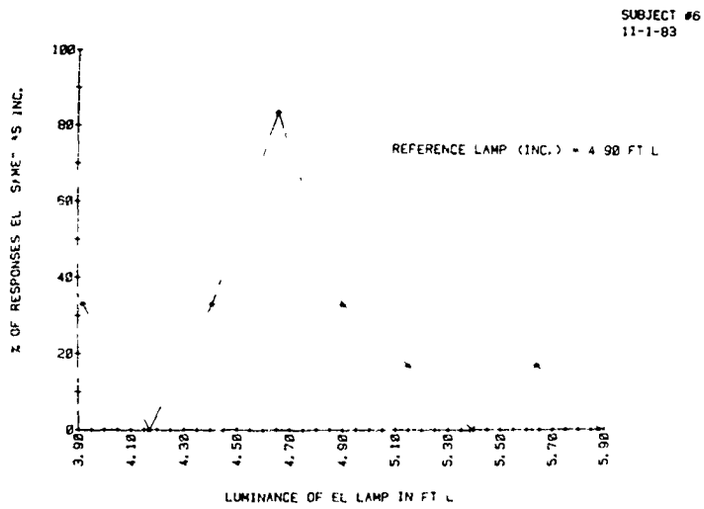

Figure 14. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #6

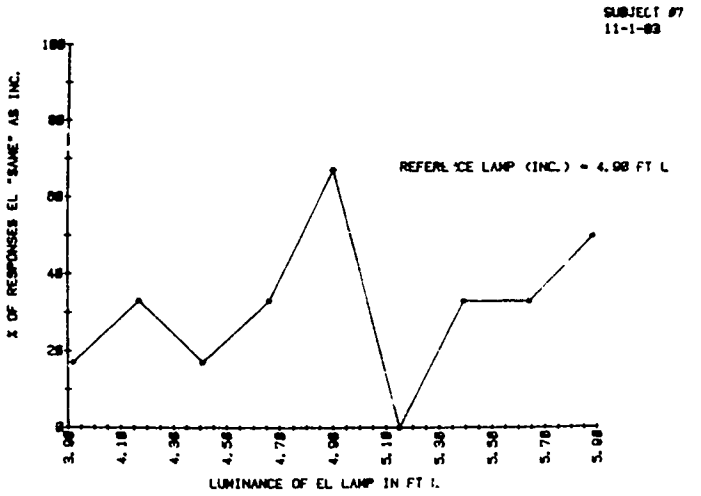

Figure 15. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #7

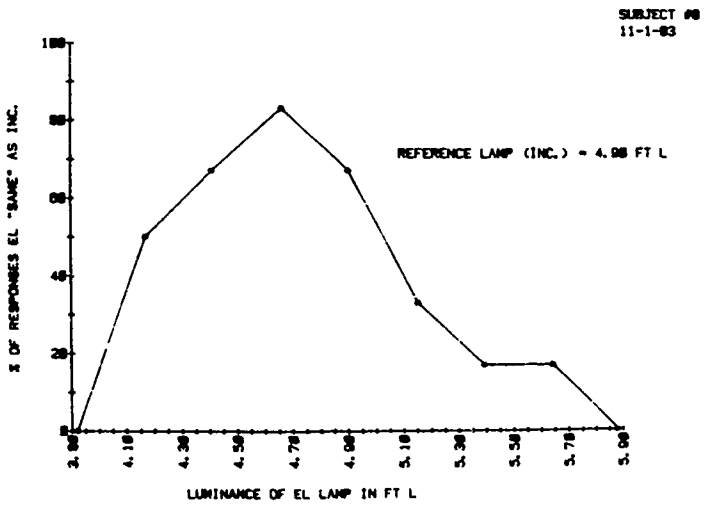

Figure 16. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #8

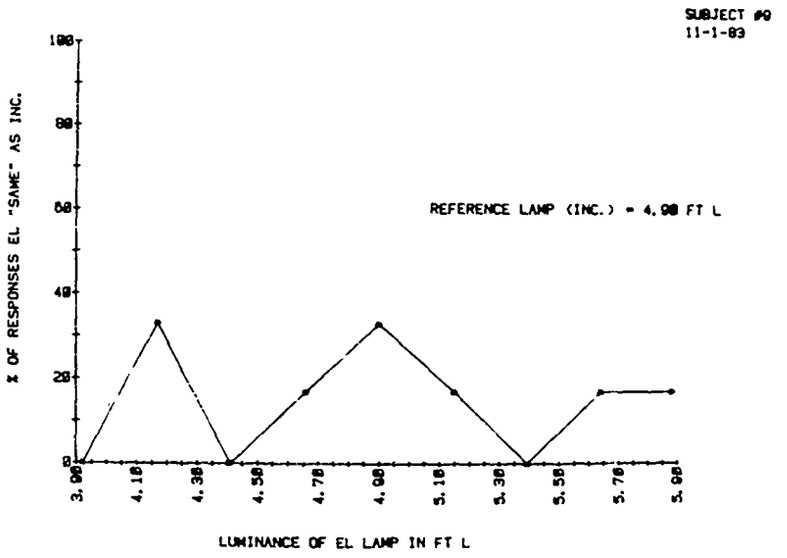

Figure 17. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #9

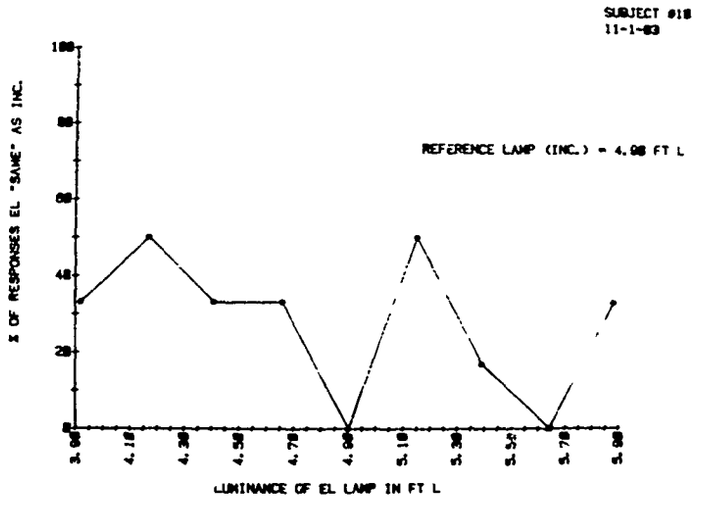

Figure 18. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #10

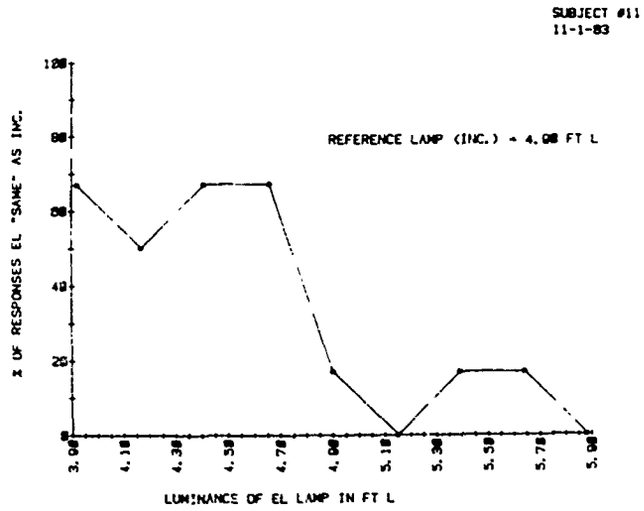

Figure 19. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #11

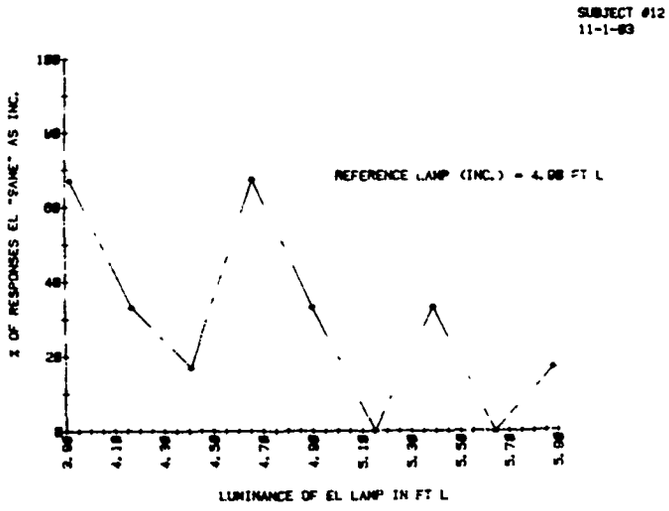

Figure 20. % "SAME" Responses vs. Luminance of EL Light in fL for Subject #12

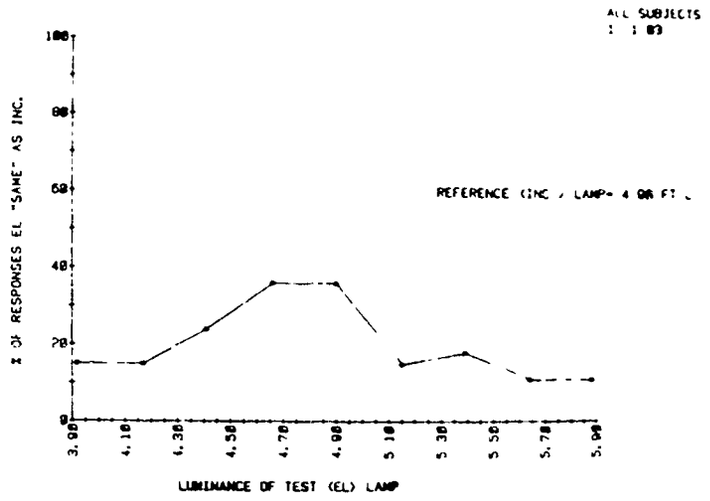

Figure 21. % "SAME" Responses vs. Luminance of EL Light in fL for ALL SUBJECTS

In a similar manner, the responses of "LOW" and "HIGH" were separately tabulated for each luminance level, and converted to percentages using the same technique described previously. Figure 22 plots the percentage of "LOW" responses for the combined data as a function of the luminance of the EL lamp, and Figure 23 plots the "HIGH" responses in a similar fashion. An examination of both of these curves also illustrates that no perceptual difference was evident between the two lamps; ie., the "LOW" response plot is a decreasing function of the luminance of the EL lamp with R = 0.97, and an increasing function is seen for the "HIGH" responses with R = 0.98.

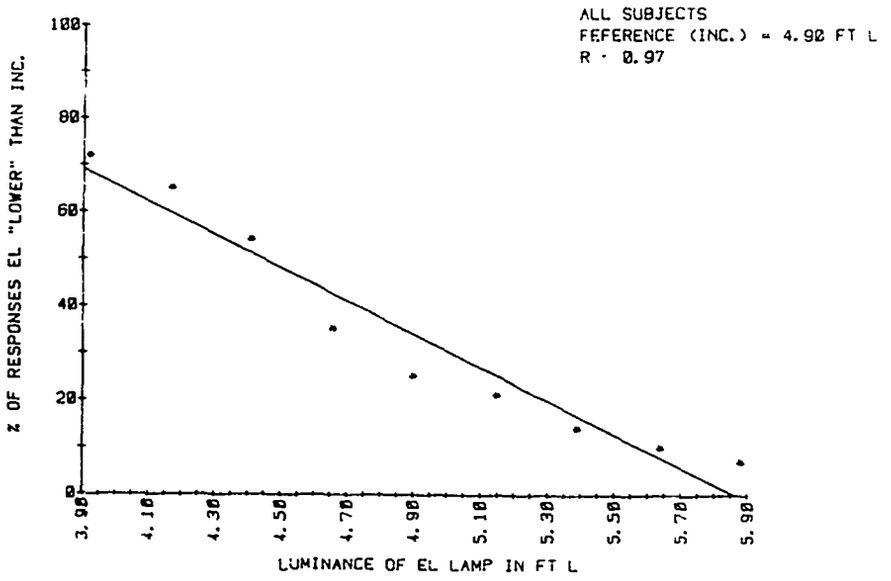

Figure 22. % "LOW" Response vs. Luminance of EL Lamp FOR ALL SUBJECTS

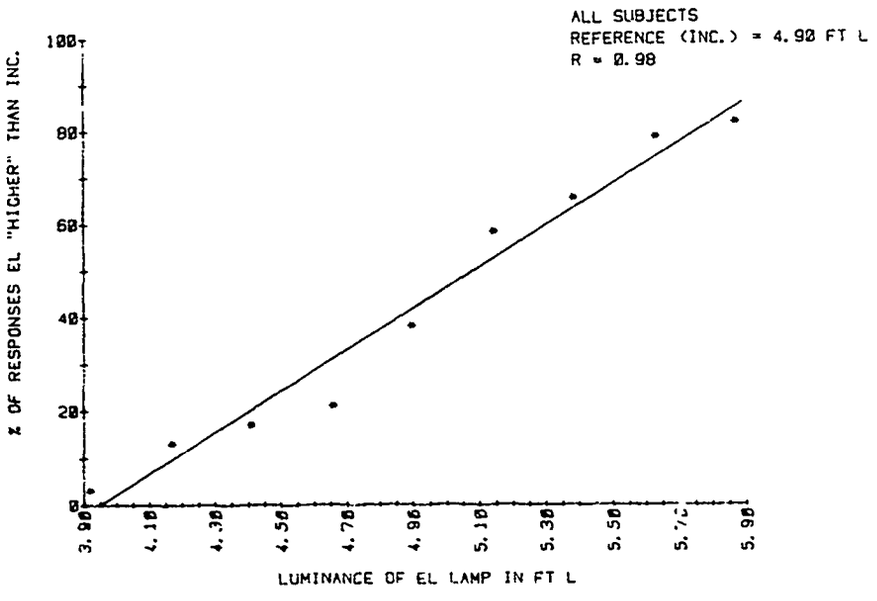

Figure 23. % "HIGH" Response vs. Luminance of EL Lamp FOR ALL SUBJECTS

CONCLUSIONS

The results indicated that once all physical parameters were equal, no perceptual difference was observed between EL and INC light. The outcome of this experiment is significant for Air Force lighting applications. No longer can EL lighting be considered a "magical" light source - one that can't be measured using photometric principles like other types of lighting. The argument that EL light is always "brighter" than INC light, and that a perceptual process is present that inhibits direct measurement of EL lighting is no longer valid. EL lighting must be evaluated on the same basis as other lighting configurations, and may be measured using currently available photometric instrumentation with no special procedures.

APPENDIX A

CONSENT FORM

BRIGHTNESS COMPARISON OF

ELECTROLUMINESCENT VERSUS INCANDESCENT LIGHTING

I, _____, having full capacity to consent, do hereby volunteer to participate in a research study entitled, "Brightness Comparison of Electroluminescent Versus Incandescent Lighting", under the direction of Dr. H. Lee Task, with principal investigator Mary Donohue Perry. The implications of my voluntary participation, the nature, duration, and purpose, the methods and means by which it is to be expected have been explained to me by Mary Donohue Perry. I have been given the opportunity to ask questions concerning this research project, and any such questions have been answered to full and complete satisfaction. I understand that I may at any time during the course of this project revoke my consent, and withdraw from the project without prejudice.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

AM
PM

_____ _____ _____

Signature Date Time

I have briefed the volunteer and answered questions concerning the research project.

_____ _____

Signature Date

APPENDIX B

OBSERVER INSTRUCTIONS

BRIGHTNESS COMPARISON OF

ELECTROLUMINESCENT VERSUS INCANDESCENT LIGHTING

After five minutes of adaptation in a darkened room, you will be looking at two blue-green circular lights, approximately one foot apart. The light on the left will be brighter, dimmer, or the same as the light on the right. After the experimenter has set the light level, your task will be to respond "HIGH" if the left light is brighter than the right light, "LOW" if the left light is dimmer than the right light, or "SAME" if both lights are of the same intensity. This procedure will be repeated for a total of 54 times. Please cover your eyes in between trials as the experimenter sets the next light level. Do you have any questions? If not, then we will proceed with the experiment. Thank you for your participation.

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